Climate Change Impacts on High Elevation Hydropower Units:
Upper American River

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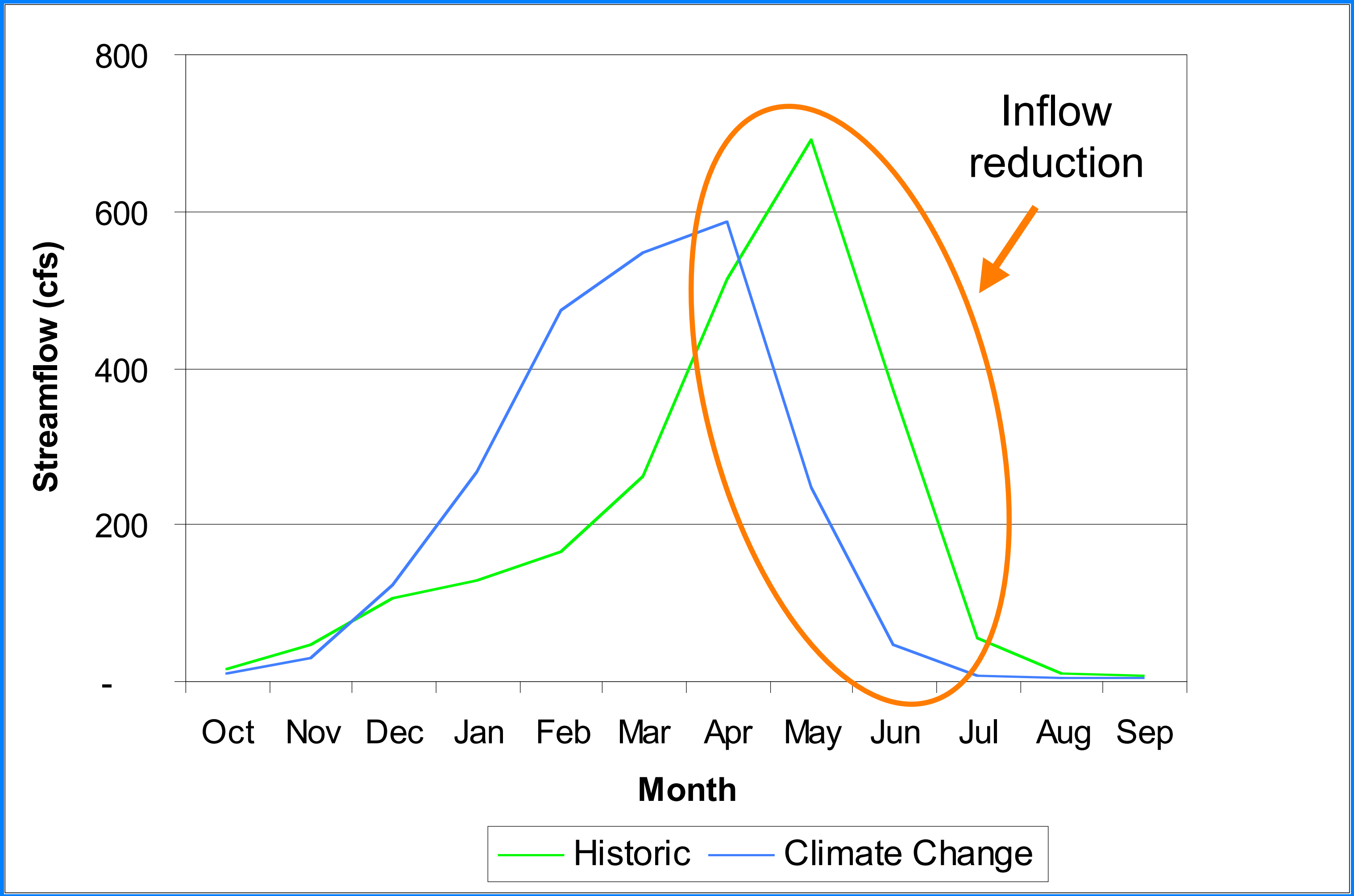
Motivation

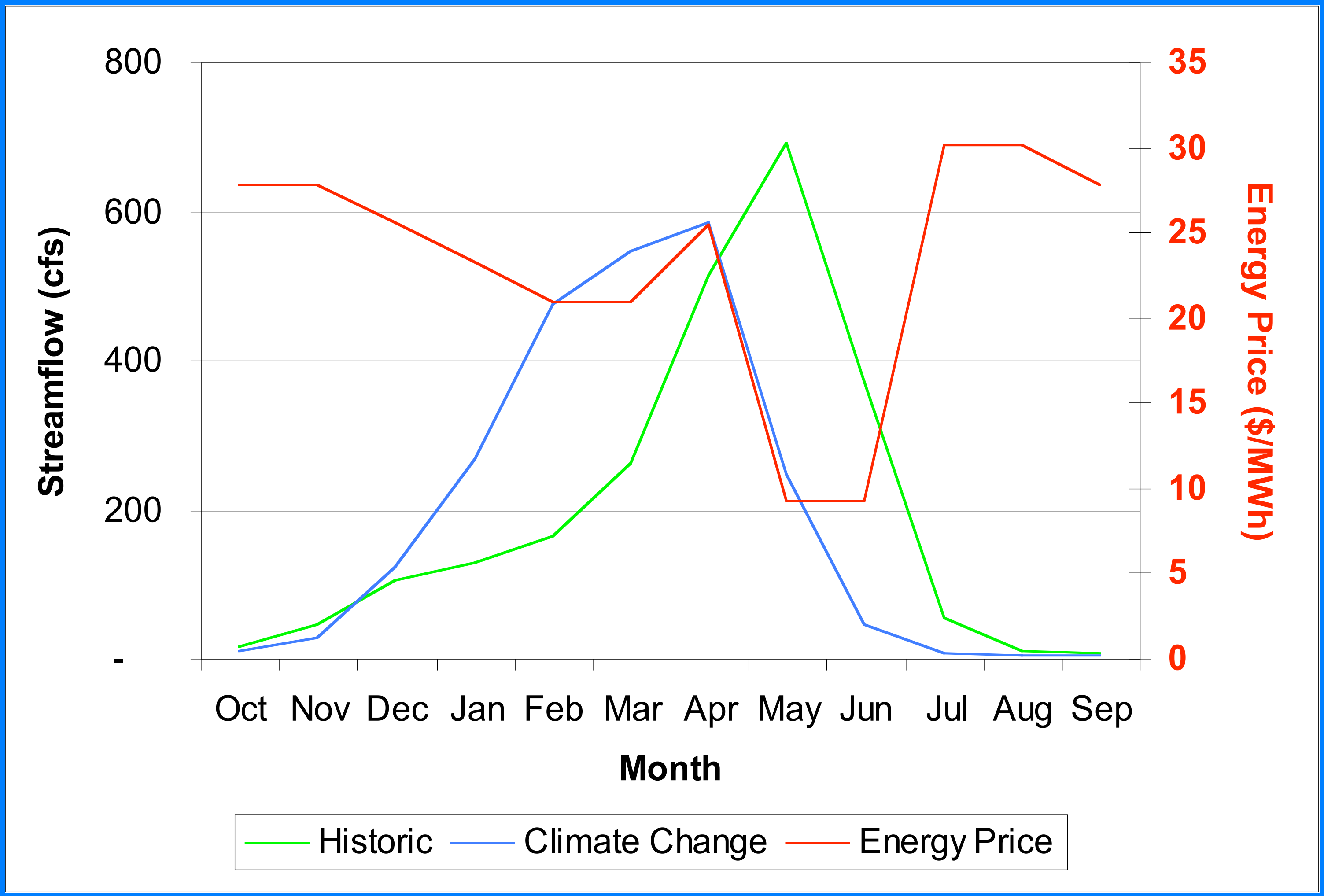
- Previous studies had focused only on low elevation hydropower
- 50% of hydropower in CA is generated at high elevation
- Climate change impacts will be different at high elevation basins

Expected Impacts



Change in hydrologic conditions

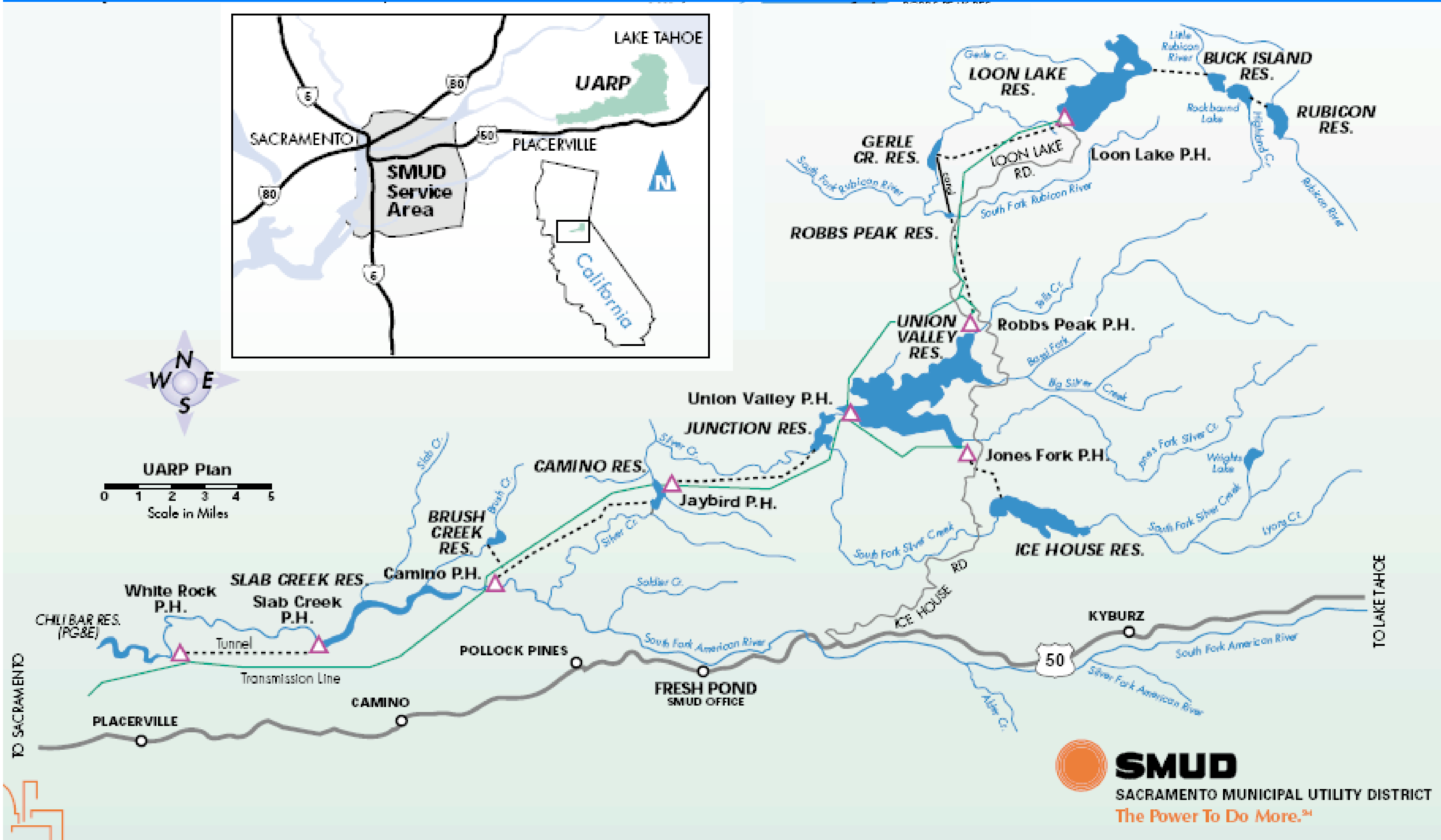
Expected Impacts



Area under study

- Sacramento Municipal Utility District (SMUD) system in the Upper American River .
- The Project includes:
  - 11 reservoirs
  - 425 TAF (524 Mm^3) of storage
  - 8 powerhouses, 688 MW

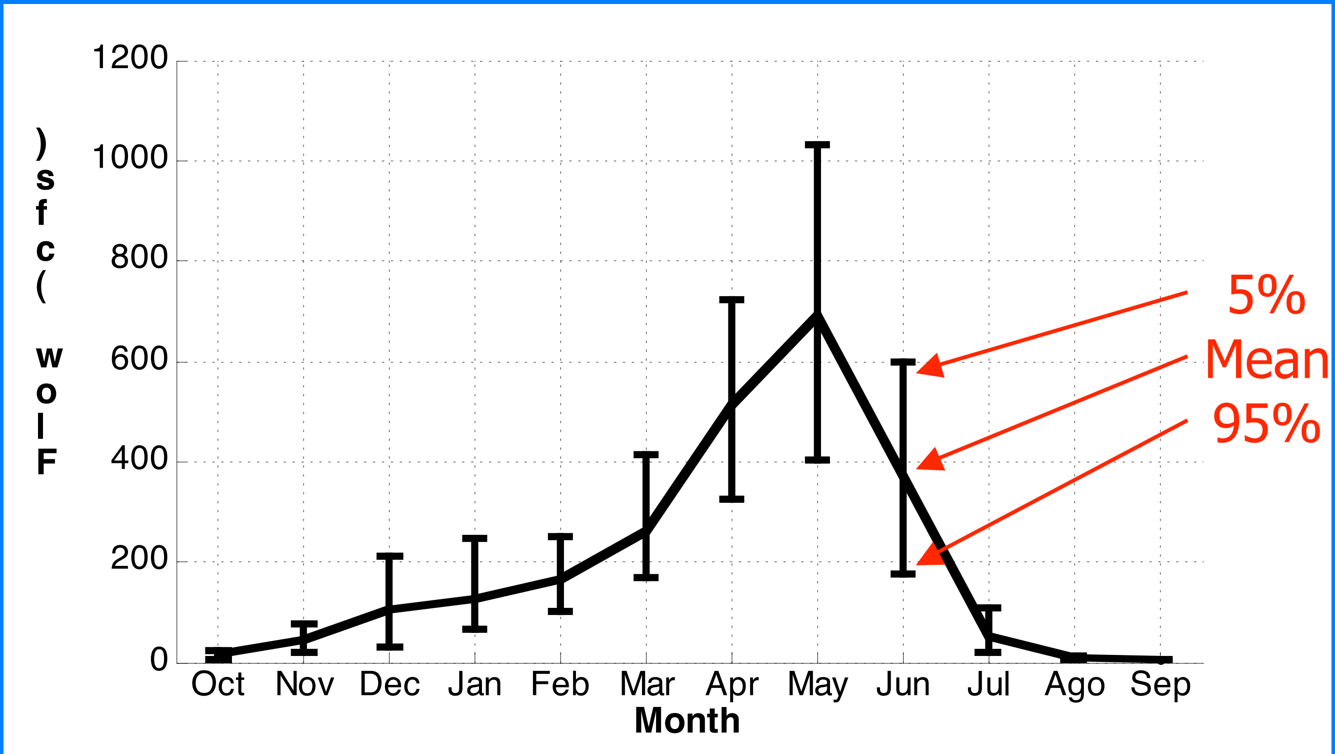
Upper American River Project



Hydrology

- Time series of daily historical “unimpaired” streamflows into the system from 1928-1949
- Focused on pre-hydropower development
- Data from USGS gages, correlation analysis and Bechtel (1958) study

Historical Hydrology



Unimpaired (pre-dam) inflows to Ice House, 1928-1949 (Historical scenario)

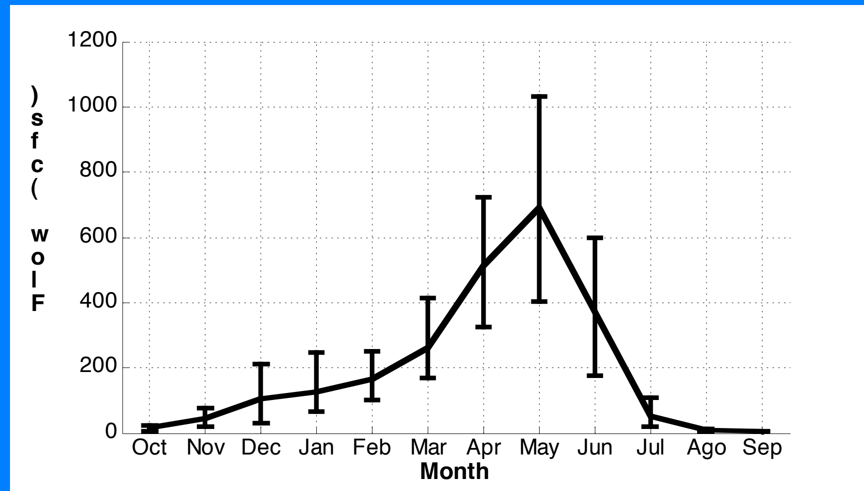
- Center of mass around May
- Two peak conditions: smaller in winter (floods) and larger in spring (snowmelt runoff).
- Flows drop significantly in July.

Climate Change Hydrology

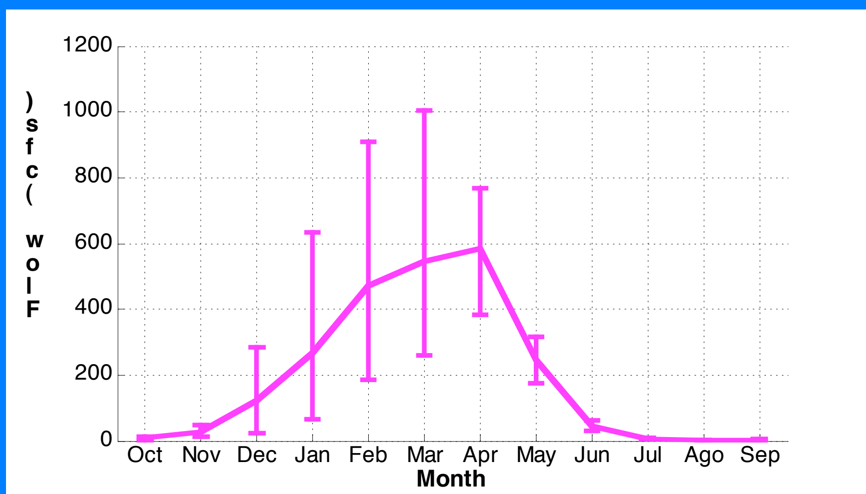
- Four GCMs/emission scenarios signals
- One "Variable Infiltration Capacity Model" grid point located close to the system
- Historical hydrology modified using perturbation ratios that compared 2070-2090 to historical VIC simulated conditions

Climate change hydrology: Inflows to Ice House

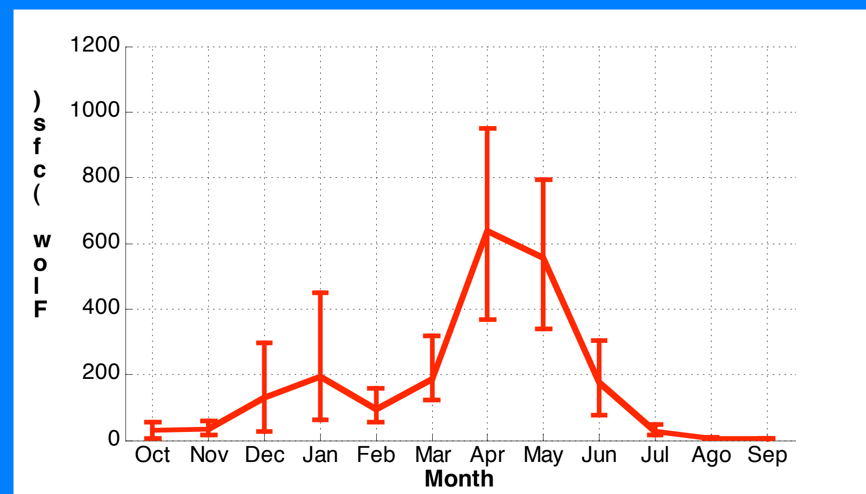
Historical



GFDLA2



PCMB1

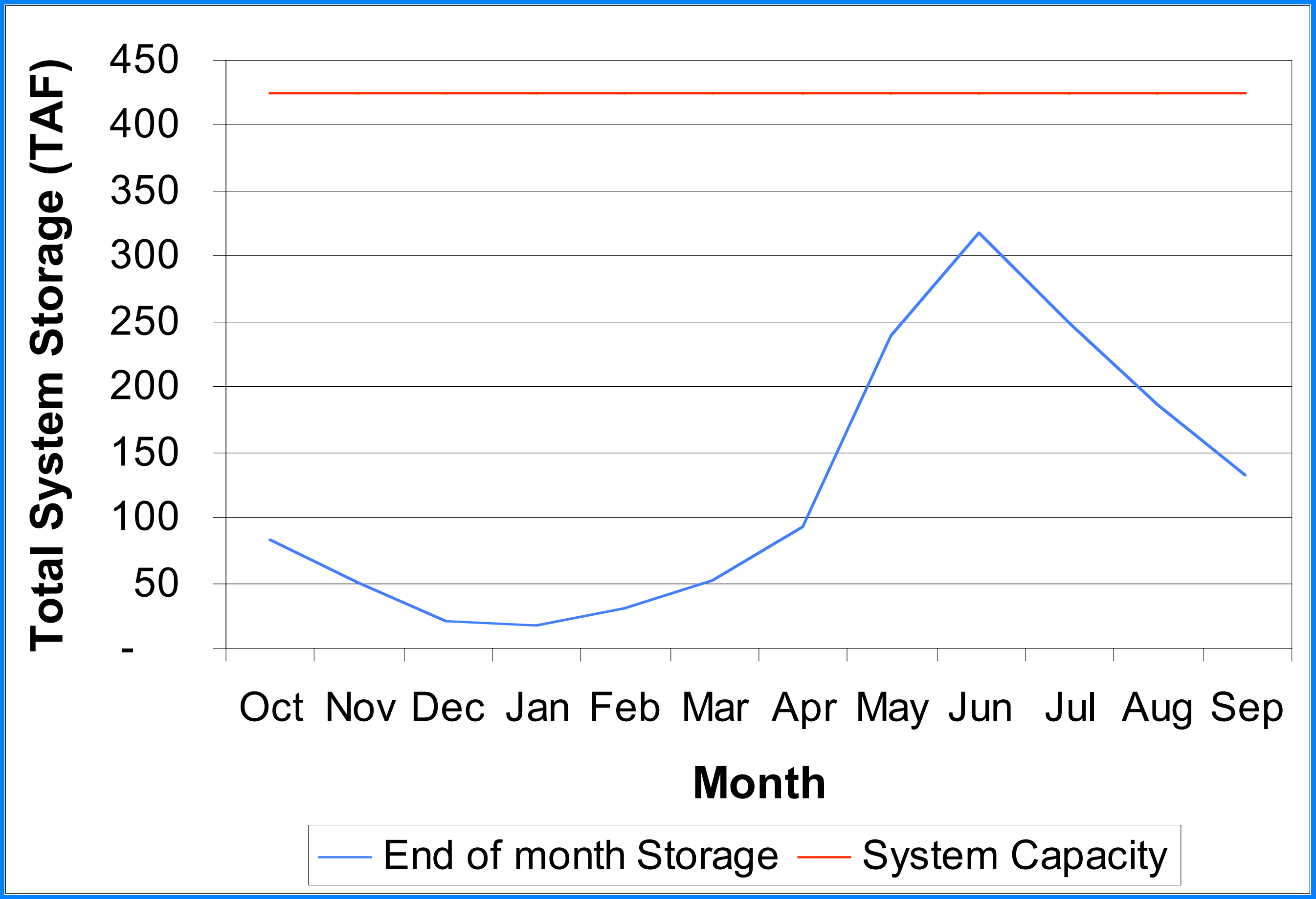


- Reduced annual streamflows in three scenarios and increased in one
- Earlier center of mass
- Larger floods in winter

Simulating system operations

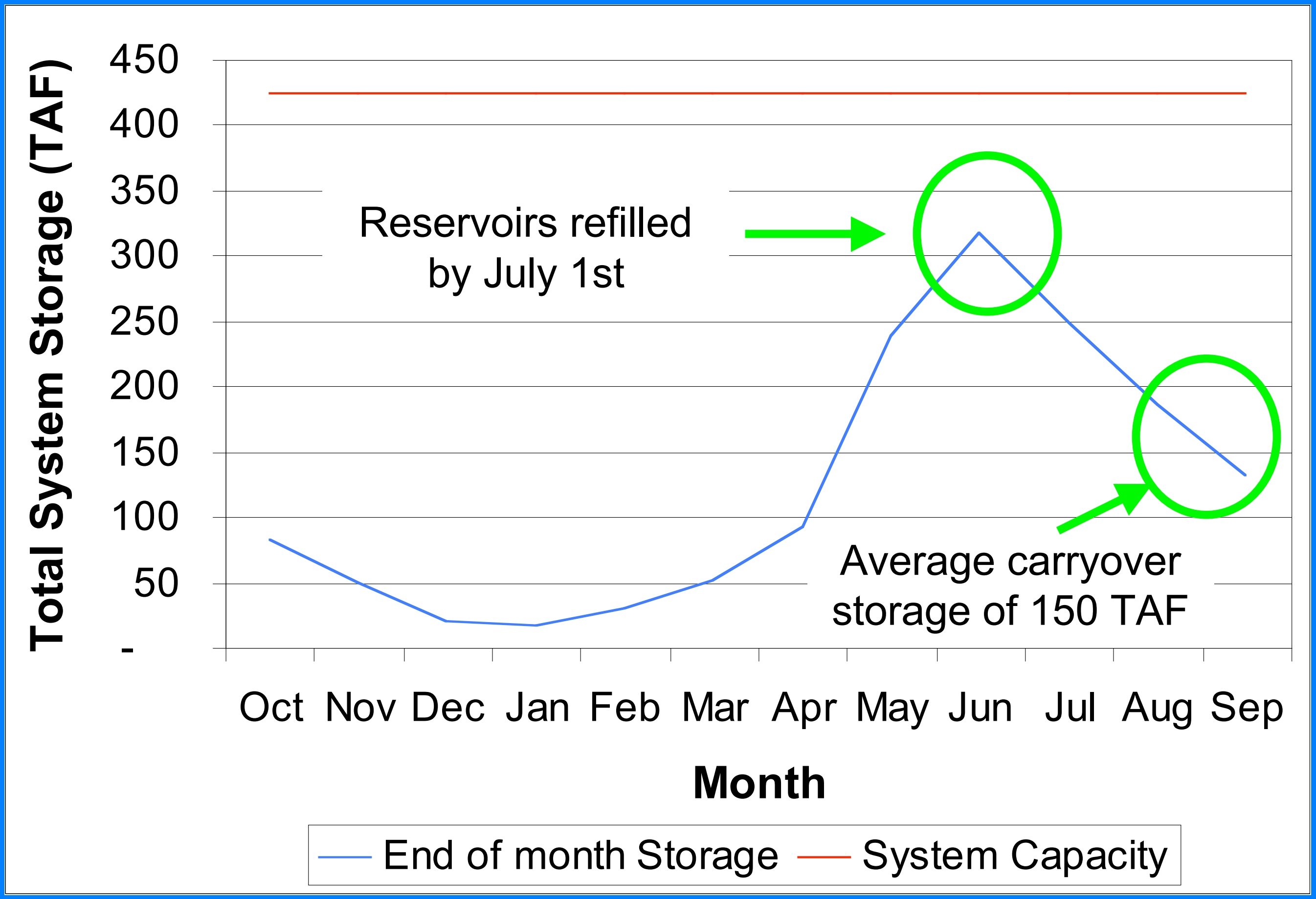
- System operation **objectives**:
  - Electricity generation, releases for peaking, real-time load following, and river management
- In practice these objectives translate into the following **guidelines rules** (SMUD):
  - To minimize spill, particularly during snowmelt period.
  - To fill reservoirs by July 1.
  - To leave sufficient carryover storage for dry years (in practice 200 TAF (247 Mm^3)).
- We modeled the system operations with a sequential multi-step **linear optimization** (constant head) on energy revenues using monthly average energy **on and off-peak prices**.

Historical Results



End of month average storage for the entire system

Historical Results



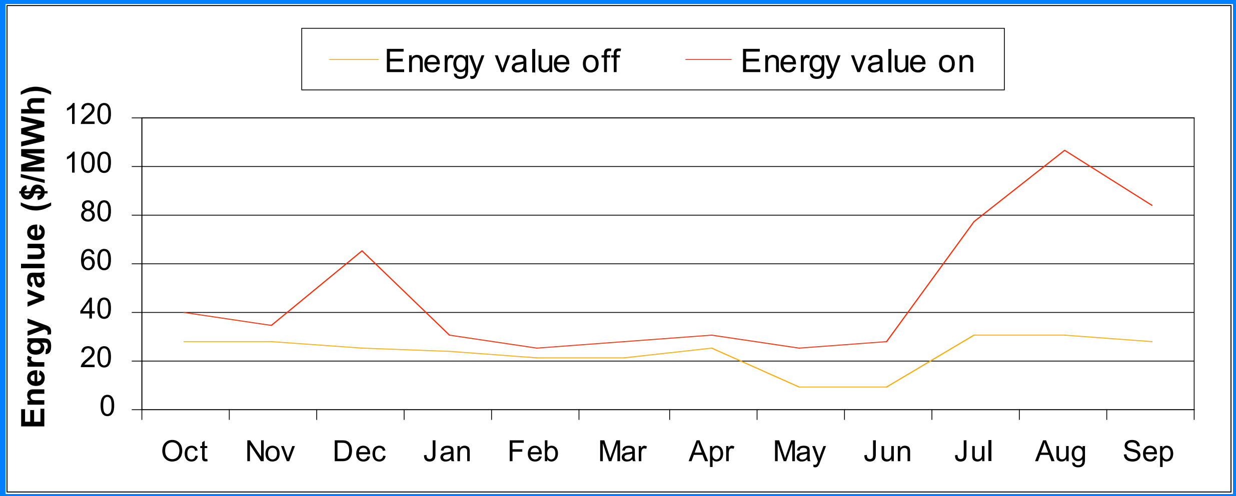
- Guidelines Operation rules are correctly simulated in the model
- Not clear though if the model is correctly simulating the occurrence of spills

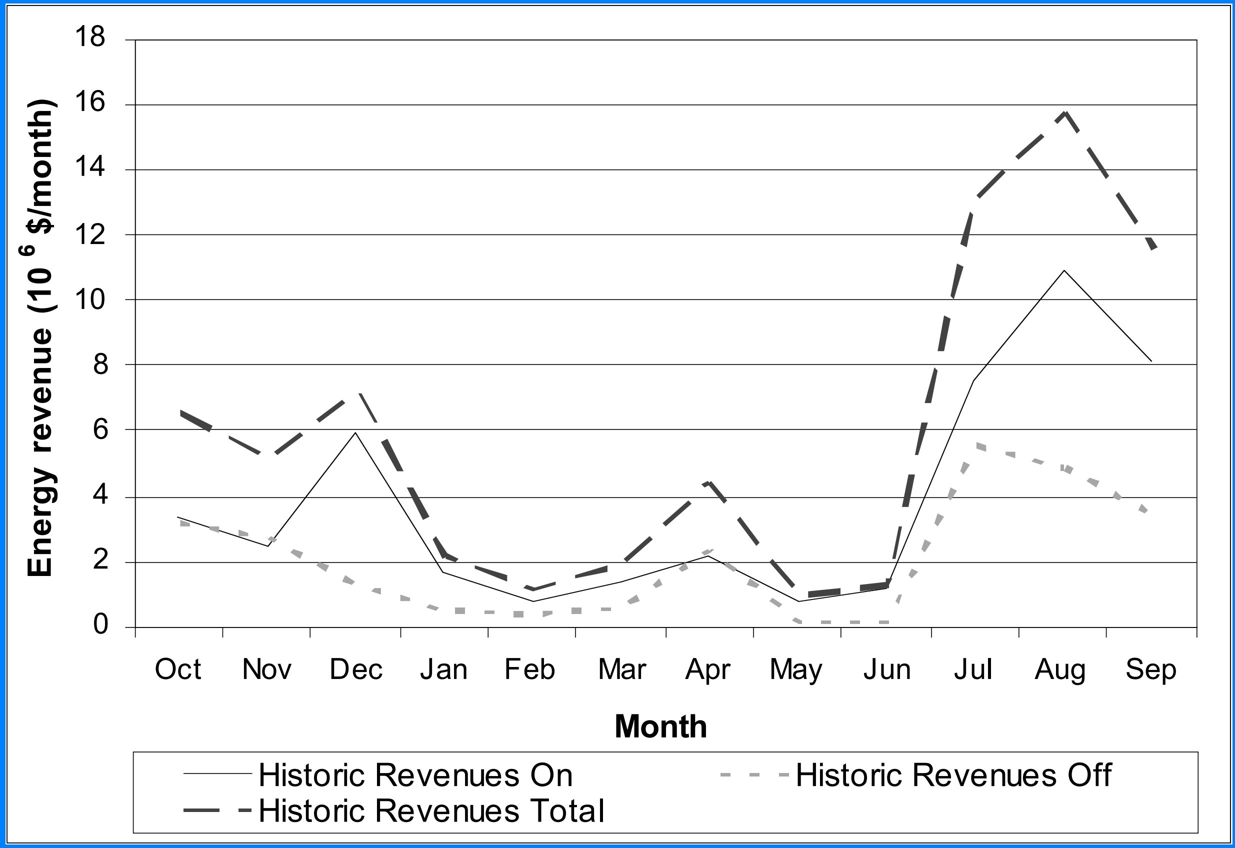
Historical Results

Average system-wide energy generation: electricity is generated in high value months

Total Generation: 1,750 GWh/yr

Total Revenues: 70 M$/yr

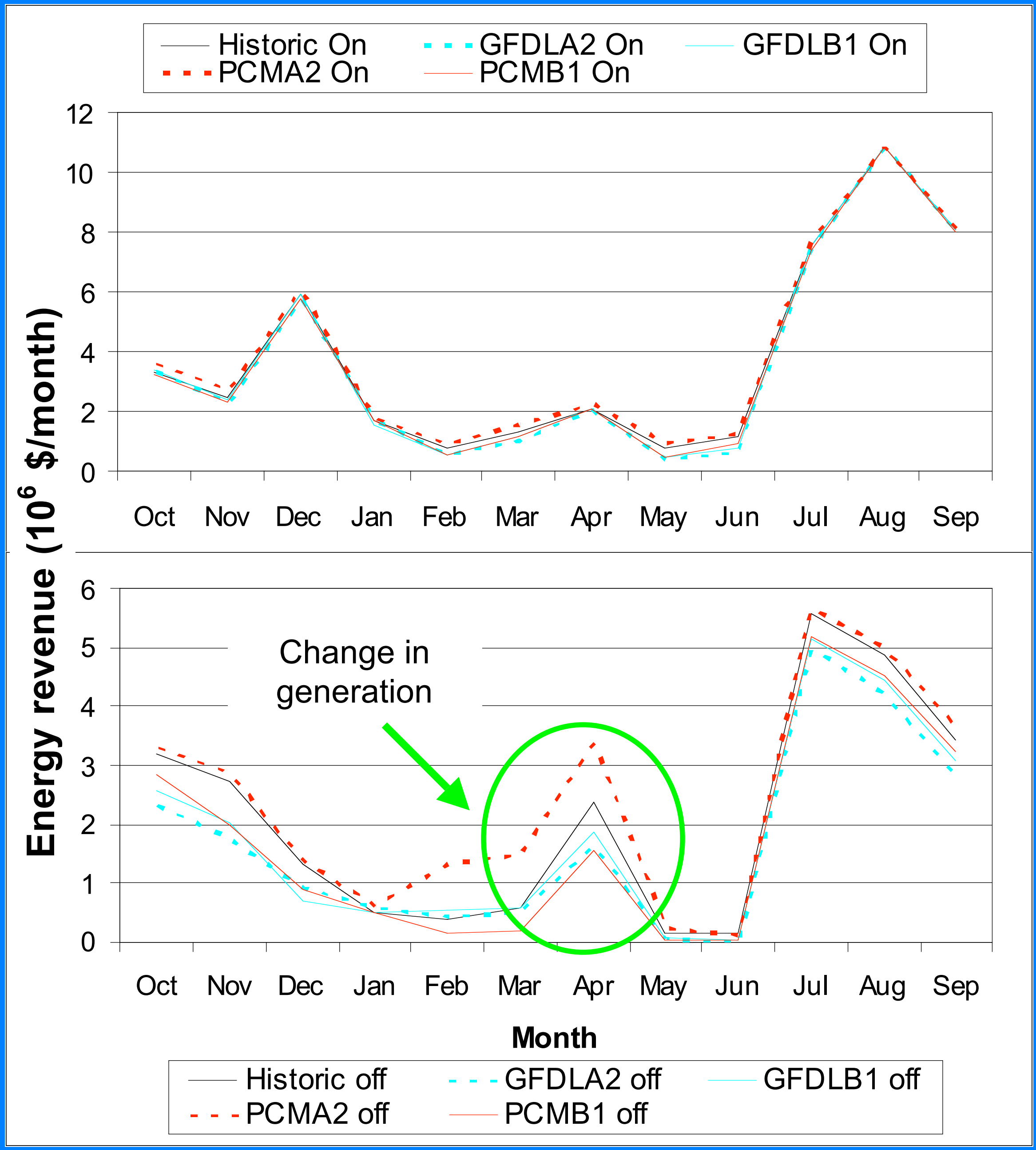




Climate change results

Average system-wide energy generation

Changes occur in off peak generation



Climate change results

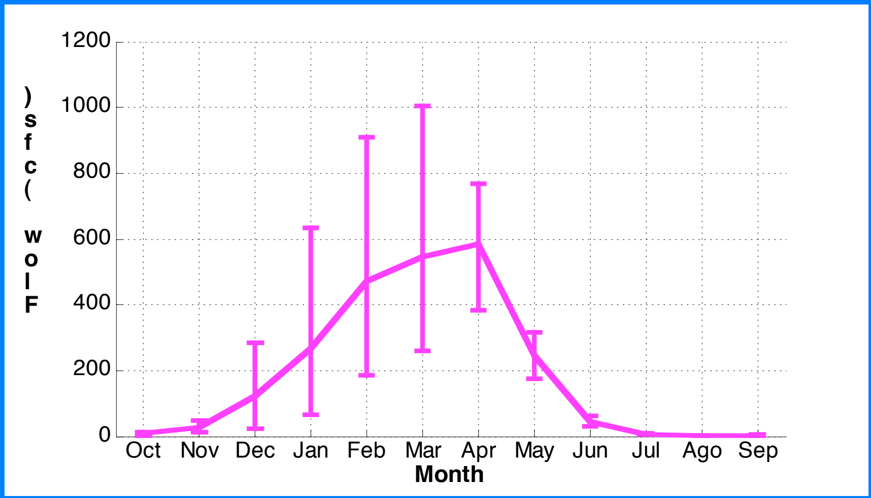
	Inflow (TAF/year)		Generation 10^6 \$/year		Generation GWh/year		Spills (cfs/month)	
Historical	491		71		1,751		39	
GFDLA2	422	86%	65	90%	1,495	85%	44	115%
GFDLB1	439	89%	67	93%	1,561	89%	45	117%
PCMA2	573	117%	77	108%	1,976	113%	97	251%
PCMB1	420	86%	66	92%	1,524	87%	19	49%

- Changes in **annual streamflows** are driving the changes in total generation.
- However, the changes in annual inflows are normally higher than the changes in generation revenues.
- This means that
  - the system under reduced inflow conditions is able to continue moving water (in time) to more valuable months
  - this ability is reduced under increased inflow conditions

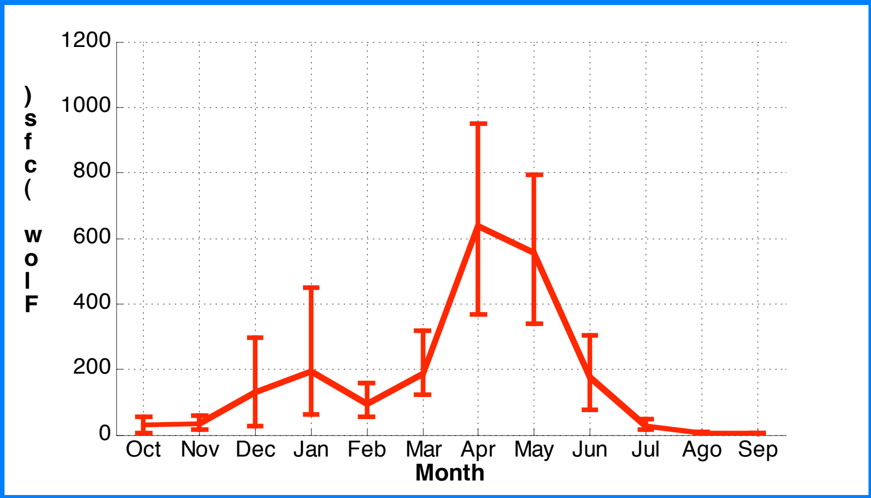
Climate change results:
Timing and winter flooding effect

	Change in Inflow	Change in Generation $/year	Change in Generation GWh/year	Change in Spills
GFDLA2	86%	90%	85%	115%
GFDLB1	89%	93%	89%	117%
PCMA2	117%	108%	113%	251%
PCMB1	86%	92%	87%	49%

GFDLA2



PCMB1



Climate change results:
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		$/year	GWh/year	
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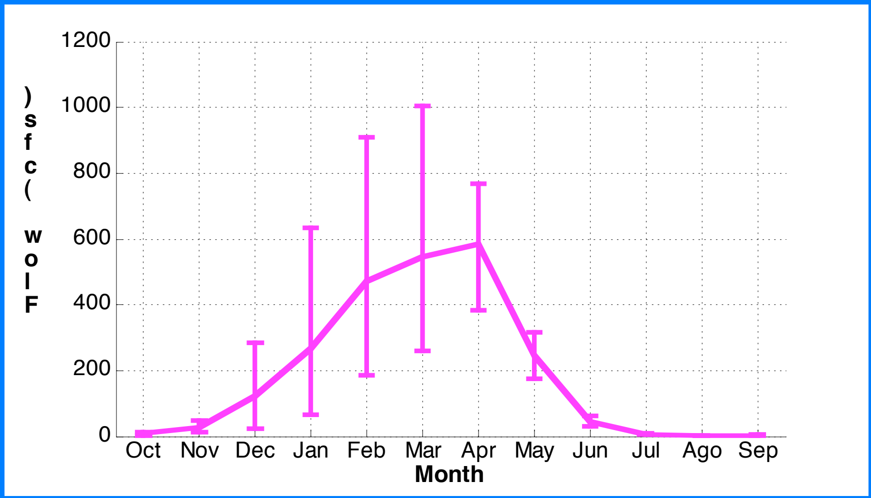

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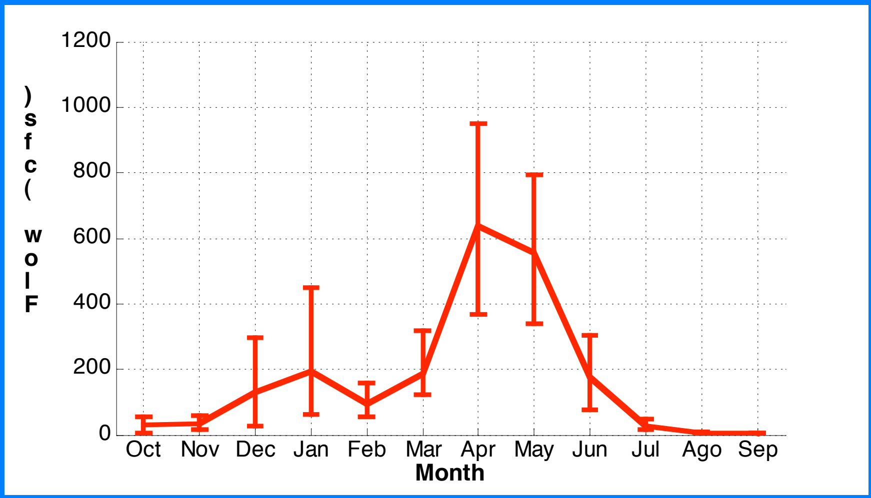
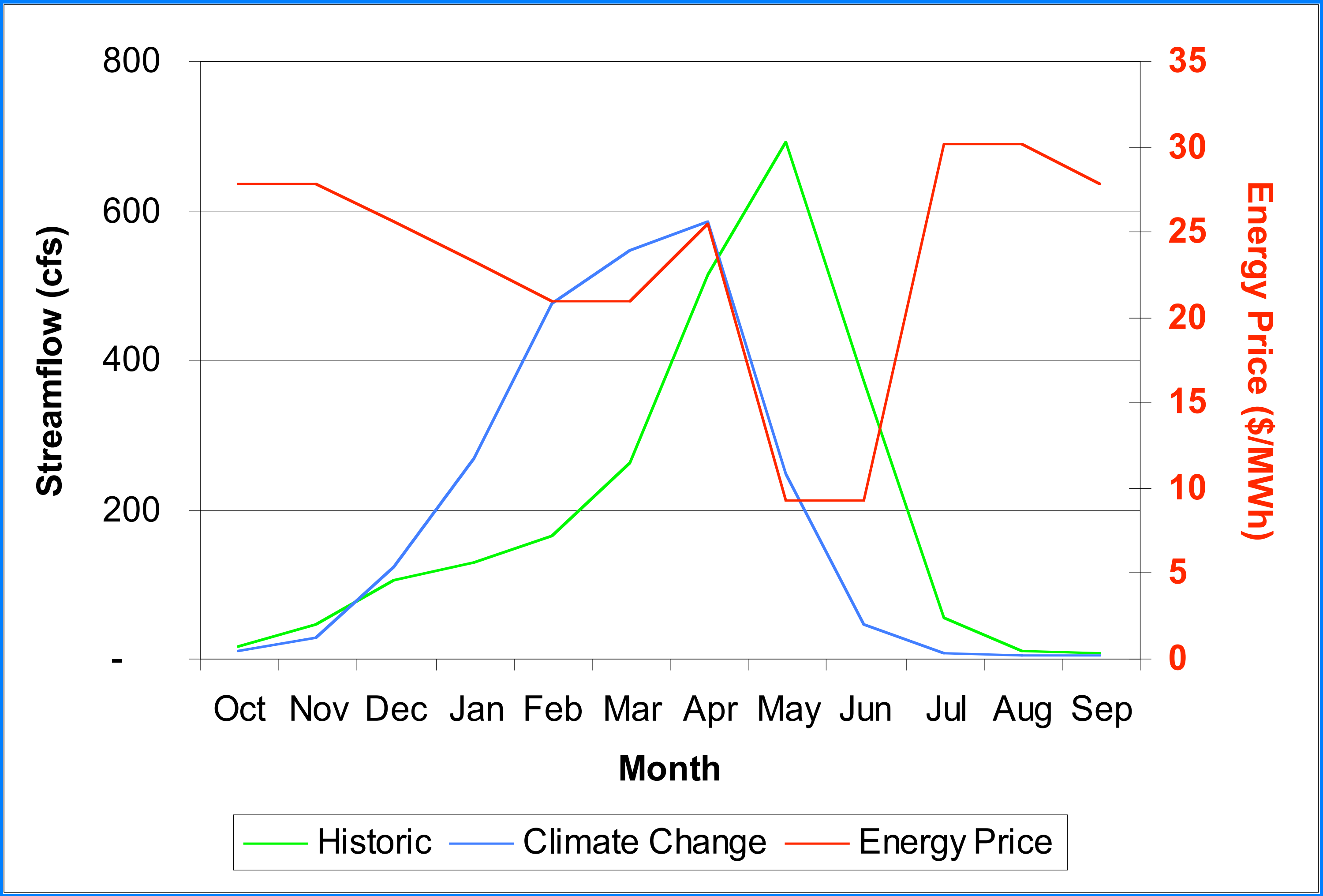


Sensitivity analysis

- Objective: stress the system and get some useful information for other systems
- Parameters changed:
  - Storage capacity
  - Energy price pattern

Expected Impacts



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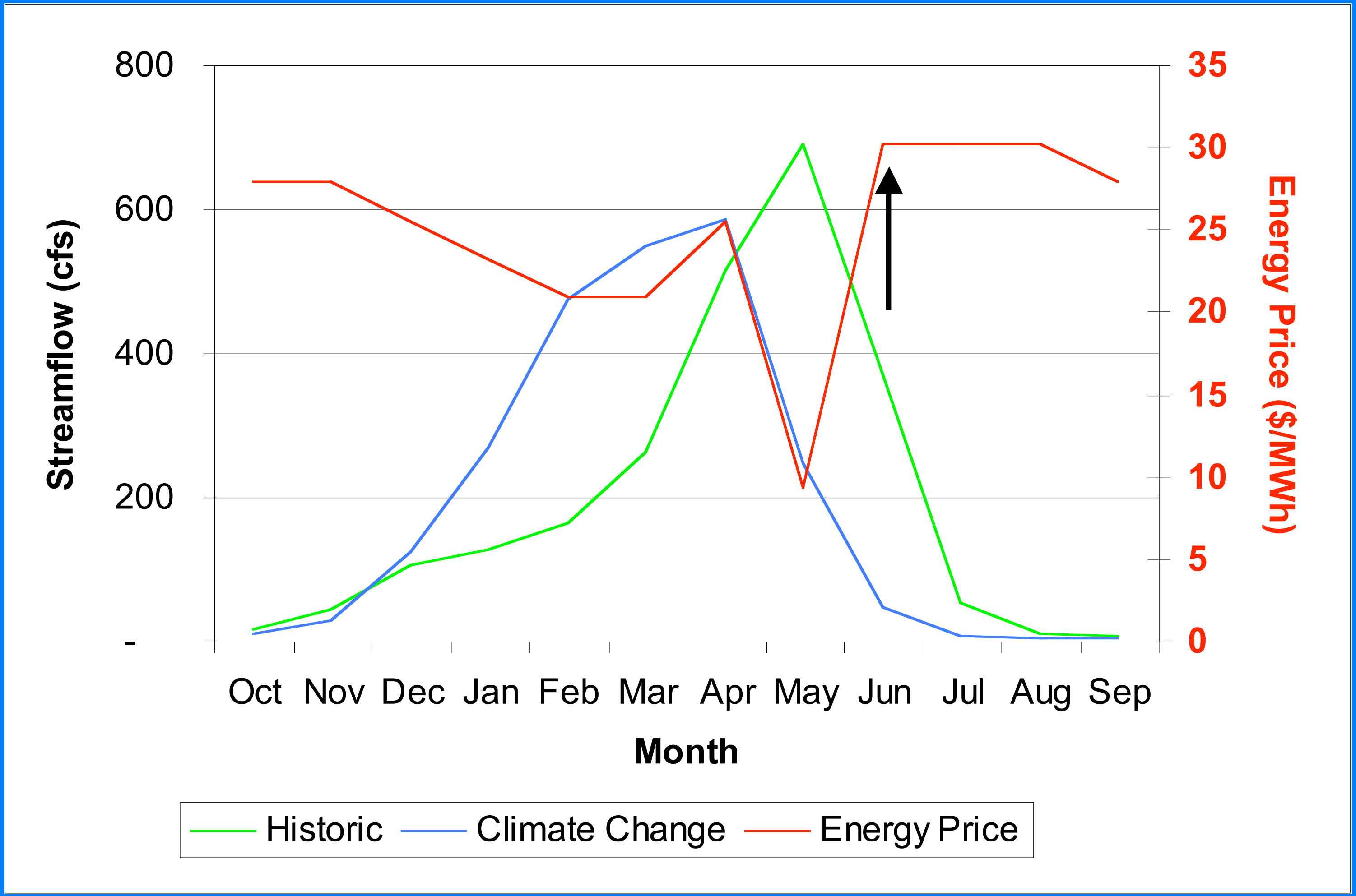

What if storage capacity was reduced and historic inflow pattern is closer to energy price pattern

Conclusions

- Hydropower generation **drops** under 3 of 4 climate change scenarios as a consequence of drier hydrologic conditions
- Drop is different in terms of energy generation than in terms of energy revenues

Conclusions (con’t)

- Small **timing** and flood effect associated with climate change

- The effects of climate change are more evident when storage capacity is reduced and the pattern of energy prices more closely matches the pattern of historic streamflow conditions

Future work

- Model enhancements
  - Reduce "**perfect foresight**" by reducing the window horizon of daily optimization. From a monthly to weekly basis. Results could be overly optimistic right now.
- Expand analysis to other basins in the Sierra Nevada
- The final impacts (both on demand and supply side) should be addressed modeling the whole California/western grid.

Acknowledgments

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